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THE AMBIENT ACOUSTIC ENVIRONMENT OF SHALLOW WATER OFF FT. LAUDERDALE, FLORIDA

By
R. J. Urick
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UNITED STATES NAVAL ORDNANCE LABORATORY, WHITE OAK, MARYLAND

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ABSTRACT

The underwater noise at two nearby sites off the Atlantic coast of Florida has been recorded at hourly intervals over periods of several weeks. At these sites, the levels of the noise were found to be highly variable, in keeping with the dynamic, changeable nature of the acoustic environment. Both the statistics of the ambient background in different octave bands, and the characteristics of the sources of noise as determined by listening to the hourly noise samples, have been obtained. For example, biological noise was found to be more prevalent during the night when the tide was high than at other times. Also, in the absence of shipping and biological sources, the level of high frequency noise was found to increase with wind speed, as it is well-known to do in deep water. Still, in spite of the busy, active underwater environment, the noise levels compare favorably with those previously reported for other shallow-water locations.

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Physics Research Department
U. S. Naval Ordnance Laboratory
White Oak, Silver Spring, Maryland

This report describes the acoustic background of the shallow waters adjacent to the NOL Test Facility, Ft. Lauderdale, Florida, where underwater acoustic tests are made from time to time. The report gives a statistical description of this background at this location, together with some of the characteristics of the responsible noise sources, that should be of interest to engineers engaged in acoustic work in this vicinity. In addition, the report is an addition to the relatively sparse literature on the acoustic background of coastal waters.

The work was done under Airtask A370 370A/WF08 121 702 - 203 assigned by the Air Systems Command.

GEORGE G. BALL
Captain, USN
Commander

D.F. Bleil

D.F. BLEIL
By direction

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INTRODUCTION

The underwater ambient acoustic background in shallow water is perhaps best known for its variability. It varies from moment-to-moment, from hour-to-hour, and from season-to-season, and therefore has a broad spectrum of variability in level in any frequency band. The reason for this variability lies in the nature of the numerous sources of noise, each of which imposes its own characteristics on the acoustic environment.

This changeable characteristic is particularly true of a dynamic underwater environment like that of coastal Florida near Ft. Lauderdale, where the measurements described in this report were made. Here there is ship traffic in the form of freighters and tankers making their way northward or southward along with, or against, the Gulf Stream. There are numerous pleasure craft engaged in sport fishing and aimless cruising. There are present a variety of biological noise-makers (though snapping shrimp are apparently absent at this location). Finally, there is the rough sea surface which contributes to the underwater background by a variety of processes (Kuo, 1968

and Marsh, 1963). Thus, the noise background in such an environment may be likened to that of a wooded area near a busy highway, where passing traffic such as passenger cars and trucks, biological noise sources such as birds and insects, and the wind as it blows through the trees, all superpose their own peculiarities on the noise picked up by a recording microphone.

The present report describes two series of measurements made over a period of several weeks each at two sites, called Site I and Site II, approximately one mile apart at the locations shown in Fig. 1.

MEASUREMENT METHOD

An Atlantic Research Corp. Type LC-57 hydrophone was planted on the bottom at Site I of Fig. 1 and connected to a previously existing cable leading to shore. Tape recordings were made of hourly samples, each one-minute long, of the noise background over a 4-week period. A few weeks later, a similar hydrophone was planted at Site II, and the procedure was repeated, again over approximately a 4-week period. The one-minute samples, amounting to approximately 500 at each site, were obtained automatically by means of a timer connected to the tape recorder. About every 3 days, when it was necessary to change tape reels, an electrical calibration of the system (exclusive of the hydrophone) was made by recording signals sent down from

shore via a separate cable-conductor to the hydrophone. The acoustical equivalent of these calibration voltages, together with the hydrophone sensitivities, had been determined previously at the NOL calibration facility at Brighton, Md. The recorded ambient noise samples were later played back in octave bands in the laboratory and averaged. At the same time, a classification of each one-minute sample by types of noise was made by listening to them, as will be described later on. Figure 2 is a sample playout, in the octave centered at 31 1/2 Hz, of the 24 hourly samples at Site I for 29 April 1969.

A total of 552 noise samples were obtained at Site I during the period 21 April to 14 May 1969, and a total of 499 samples were obtained at Site II between 1 July and 26 July 1969. Weather data was provided by the regular Weather Bureau observations made hourly at the Ft. Lauderdale International Airport about 4 nautical miles West of the hydrophone sites. No attempt was made to identify or monitor ship traffic during the experimental period.

LEVEL DISTRIBUTION CURVES

Cumulative distribution curves of measured noise levels at the two sites are given in Figs. 3 and 4. These show the percentage of noise samples having levels greater than the value shown as abscissa, expressed as spectrum levels reduced from octave band levels by applying a "correction"

equal to 10 times the logarithm of the bandwidth. This "correction" is not valid for noises containing a strong line component in any octave band, but is adopted as a convention to facilitate comparison with other data appearing in the literature. Thus, Figs. 3 and 4 give the fraction of the time that one-minute averages of noise may be expected to be greater than a given level. The curves are notably skewed toward the high side, indicating an excessively high number of noisy samples. But if these excessively noisy samples are neglected and a straight line is drawn through the remaining samples on each curve, the indicated standard deviation of the distributions becomes about 6 db, with a tendency to be greater at low frequencies than at high. At Site I, no valid measurements could be obtained in the 63 Hz octave due to the occurrence of 60-cycle hum pickup on the recordings.

COMPARISON OF THE TWO SITES

In Figs. 3 and 4, the average ambient level of the deep sea is indicated by the dashed lines for the conditions of sea state 2 and heavy shipping (Knudsen, et al, 1948; Urick, 1967, Chap. 7). On comparing the measured median (50%) levels at the two sites with the deep water averages, we observe that Site I is less noisy at low frequencies and is more noisy at high frequencies th n the deep sea; Site II is about equally noisy at low frequencies but is much quieter at high frequencies.

The contrast between the noise spectra at the two sites is shown more clearly in the replot of the data given in Fig. 5. This shows the median level in each octave band, along with a vertical line giving the 5% confidence limits of the median. This signifies that there is only a 5% chance that the true median in each band lies above or below the indicated limits, assuming that the levels are normally distributed.

We observe that there is a statistically significant difference (at the 5% confidence level) between the noise environments at the two sites. There is more low frequency noise and less high frequency noise at Site II than at Site I. This is a result of a different relative proportion of the sources of noise occurring at the two locations, as well as water depth and distance from shore. For example, Site II is located close to the tracks of southbound merchant shipping traveling against the Gulf Stream. Another factor concerning Site II is the generally lower wind speed that prevailed during the later period of the year when the measurements were made at this site.

NOISE SOURCES

It was observed long ago (Knudsen, et al., 1944) that there are three general types of ambient noise in deep

and shallow water. One class of noise is associated with water motion at and near the sea surface; this kind of noise may be called <u>wind noise</u> because of its obvious connection with the wind. Another kind of noise is caused by a variety of soniferous underwater animals, and can be called <u>biological noise</u>. The third type, called <u>ship noise</u>, is the result of near-by or distant ship traffic, ranging from large slow merchant men to high-speed small sports craft.

These three noise types, when in their pure form, have distinct audible characteristics. Wind noise is notably nondescript, having no tonal or transient structure evident to the ear. Biological noise consists of chirps, crackles, pops, groans, that are sometimes more or less continuous, but are more typically intermittent and irregular; there was no evidence in any of the samples of the continuous crackle made by snapping shrimp and only one of the samples contained the well-known sound of porpoises. Ship noise is characterized by the kind of amplitude modulation called propeller beats, having a modulation rate dependent on the speed of rotation of the propeller shaft and therefore on the size of the noise-making vessel. Because of these differences, the three types of noise are readily distinguishable by the ear.

Accordingly, all the samples were listened to and were assigned to one of the three noise categories. In many cases the assignment was definite and easy, in others difficult, and in a few cases, where biologic

noise and ship noise occurred about equally, no single type of distinction could be made. In nearly all cases, some amount of subjective judgement in class assignment was required, since "pure" forms of the noise types, uncontaminated by others, occurred only rarely.

Table 1 is a breakdown by noise types giving the number of samples and the average level at three frequencies for each type. A total of 8 samples contained both ship and biological noise and were excluded from further analytical consideration.

Figure 6 shows octave band spectra of relatively pure examples of each of the noise types found at Site II. It is evident that ship noise is relatively rich in low frequencies and has a high spectral slope; wind noise is rich in high frequencies and has a low spectral slope; biological noise, of the kind appearing in this data, appears to have an intermediate spectral slope, with an intermittent and often tonal quality that makes it readily identifiable to the listener.

WIND NOISE

Figures 7 and 8 show the dependence of the average level of wind noise in three frequency bands upon wind speed at each site. Clearly this dependence is stronger at high frequencies than at low, possibly because of

contamination by ship noise at low frequencies. There was a scarcity of high wind speed samples at Site II because of the absence of strong winds during the early summer when the site was occupied.

The slope of the 2000 Hz levels at Site I amounts to about 1/2 db per knot of wind speed, a slope nearly the same as that measured by Piggott (1964) for wind-dependent noise in 36 to 51 meters of water on the Scotian Shelf. Also, both the slope and the levels themselves at Site I are about the same as the well-known Knudsen curves (Knudsen, et al., 1948) for deep water; however, this agreement may well be no more than coincidental.

No effect of wind direction could be detected in the data; the levels for easterly (on-shore) winds were not appreciably different from those for westerly (off-shore) winds at the same wind speed.

Rain was found to have an effect on the noise level of the low-wind noise samples. Figure 9 is a comparison of the median spectra of wind noise in the absence of rain with the levels measured when it was raining, for wind speeds of 10 knots or less. The small numbers show the number of rain samples occurring at the particular level in each octave band. The vertical bars show the

5% confidence limits on the no-rain samples. It is evident, without statistical testing, that rain does indeed affect the level of wind noise. The increase amounts to 5 to 10 db at frequencies of 1 kHz and above. Rainfall, as a source of underwater noise has been studied in the past both theoretically (Franz, 1959) and quantitatively (Furduev, 1966).

BIOLOGICAL NOISE

The biological noise samples at both sites had a strong tendency to occur during the nighttime hours when the tide level was high. Figure 10 shows the occurrence of the 41 biological noise samples of Site I and of the 13 samples at Site II, by tide height and time of day. Moreover, when biological noise does occur, it tends to be somewhat higher during the middle of the night than after sunset and before sunrise. This effect is illustrated by Fig. 11, where one sees a tendency of the biological noise samples to have a higher level during the hours of maximum darkness. At the same time, as shown in the lowermost plot, the number of samples classed as biological tends to increase steadily during the night, and to become greatest just before dawn. What these effects signify in terms of the soniferous population of the area, the species involved, and the acoustic output of any one type of noisemaker is, of course, not clear,

since we made no attempt to identify the biological sounds nor to continuously monitor the noise throughout the night.

SHIP NOISE

Although, as we have just seen, biological noise samples occurred most commonly at night, ship noise samples tended to occur more commonly during the day. At the bottom of Fig. 12 is shown an hourly plot of the number of samples classed as ship noise that happened to occur at a particular hour of the day. The ship noise samples were further divided into a "high frequency" class and a "low frequency" class that are presumably due to small craft and large ships, respectively. High frequency ship noise shows an evident diurnal variation in the number of samples, caused no doubt by the greater abundance of small craft by day. The number of low frequency ship samples remains constant around the clock, as one would expect from the behavior of large merchant ship traffic. As shown by the hourly plots of level in Fig. 12, the level of all the ship noise samples combined, when plotted by hour of the day, remains constant at low frequencies, and tends to be somewhat higher at high frequencies during the daytime hours than at night. A comparison of weekend versus weekday noise levels did not show any apparent difference.

COMPARISON WITH OTHER DATA

The present measurements are compared in Figure 13 with data measured at other locations and published in the literature. Over the mid-frequency range, the present data compare closely with the prior measurements (except for curve E-E, off Asia), but tend to be somewhat higher at low frequencies and lower at high frequencies.

SUMMARY

The findings of the analysis may be summarized as follows:

1. A series of one-minute noise samples, taken hourly over a 4-week period at two locations off Ft. Lauderdale, Florida, has yielded statistical data on the acoustic background in a dynamic, changing, shallow-water environment (Figs. 3 and 4).
2. The distribution of levels is non-normal, with an excessive occurrence of high levels caused by nearby strong noise sources. Excluding these noisy samples, the standard deviation of the levels is of the order of 6 db, and tends to be higher at low frequencies than at high (Figs. 3 and 4).
3. The noise spectra at the two sites are different. There is less low frequency noise, and more high frequency noise, at the shallower site in 34 m. of water (Site I) than at the deeper site in 150 m. of water (Site II) about

a mile away. This is due to a different relative abundance of the noise sources at the two sites and possibly to unknown differences in sound propagation (Fig. 5).

4. Over much of the frequency range, the median levels at Site II are about the same as those in the deep sea under the conditions of sea state 2 with heavy shipping. The levels at both sites are roughly the same as those measured at other shallow water locations and reported in the literature (Fig. 13).

5. An aural classification of the samples has been made by biological noise, ship noise, and noise having no particular character, here called wind noise. These types seldom occur in their pure form, and the samples represent mixtures of the three. The spectra of these noise types, when comparatively uncontaminated by others, are different (Fig. 6).

6. The levels of the wind noise samples at high frequencies show an increase with wind speed for wind speeds higher than 10 knots. At low frequencies, no wind speed dependence is evident, possibly because of contamination by ship noise. At low wind speeds, there is also little or no dependence on wind speed, possibly for the same reason, or possibly because of the emergence of another source of noise under near-calm conditions (Figs. 7 and 8).

7. Wind direction had no effect on the level of wind noise at a given wind speed, suggesting that such noise

is locally generated in the vicinity of the hydrophones. Rain was found to raise the level of noise at wind speeds of 10 knots and less by approximately 5 db (Fig. 9).

8. Biological noise occurs strongly at night and is more common at high tide than at low tide. When it occurs, its level tends to be higher in the middle of the night than just after sunset and before sunrise (Figs. 10 and 11).

9. The occurrence of ship noise also is diurnally variable, but is more common by day than by night because of the preference of pleasure and fishing craft for daytime operation. The number of samples with low frequency ship sounds that are typically due to large passing ship traffic shows no diurnal variability. At low frequencies, the average level of noise is constant around the clock; at high frequencies, it is somewhat higher by day than by night because of the greater number of small craft and their closer proximity to the measurement hydrophone (Fig. 12).

10. The analysis has dealt with only a part of the overall spectrum of variability of the acoustic environment. Neither the fast fluctuations within the one-minute samples (Fig. 2), nor slow fluctuations having periods of weeks or months, have been studied. A much longer observation period would be needed to reveal the seasonal and

annual changes that are doubtless an important part of the variability of the noise background.

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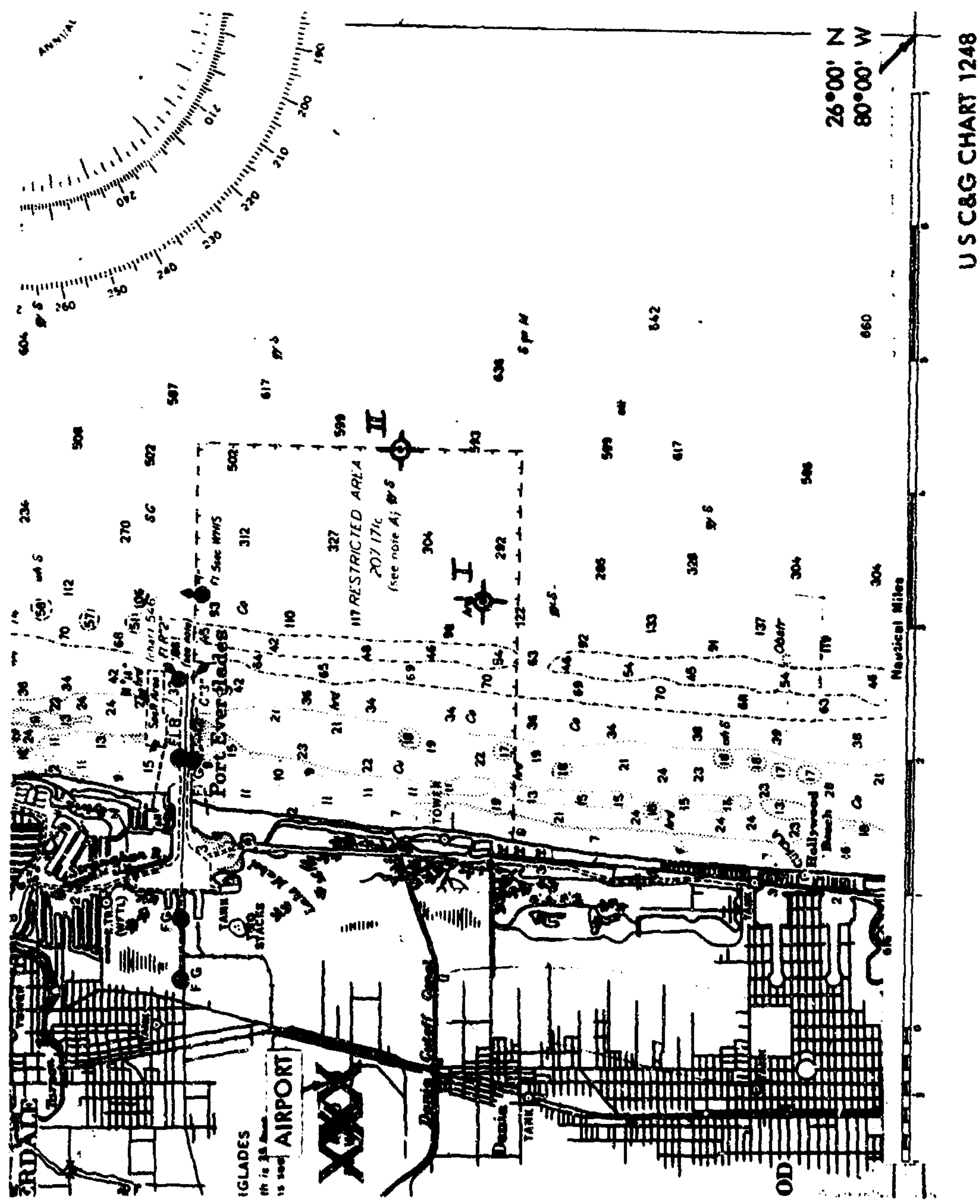

FIG. 1 HYDROGRAPHIC CHART OF THE FT. LAUDERDALE AREA SHOWING THE LOCATION OF THE TWO HYDROPHONE SITES.

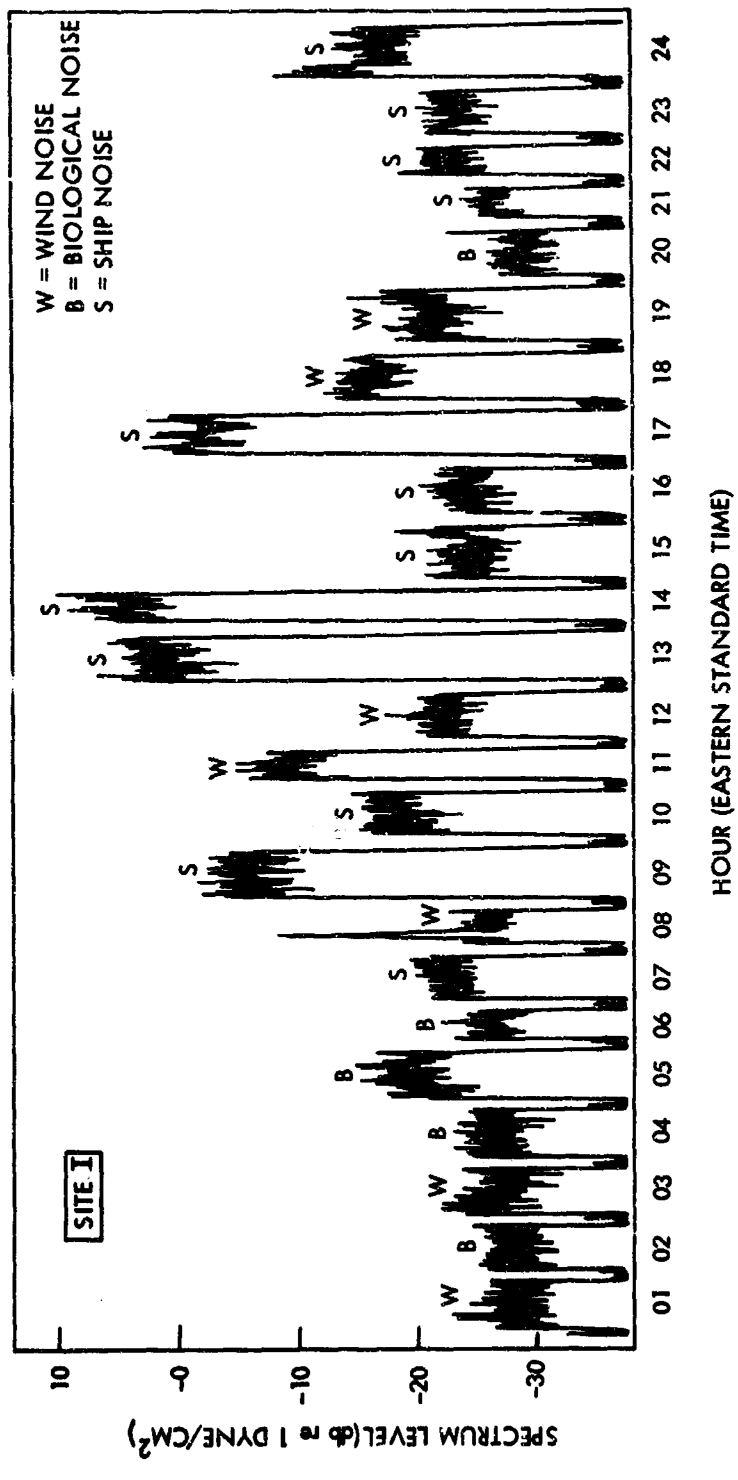

FIG. 2 SAMPLE PLAYOUT IN THE OCTAVE CENTERED AT 31 1/2 Hz AT SITES

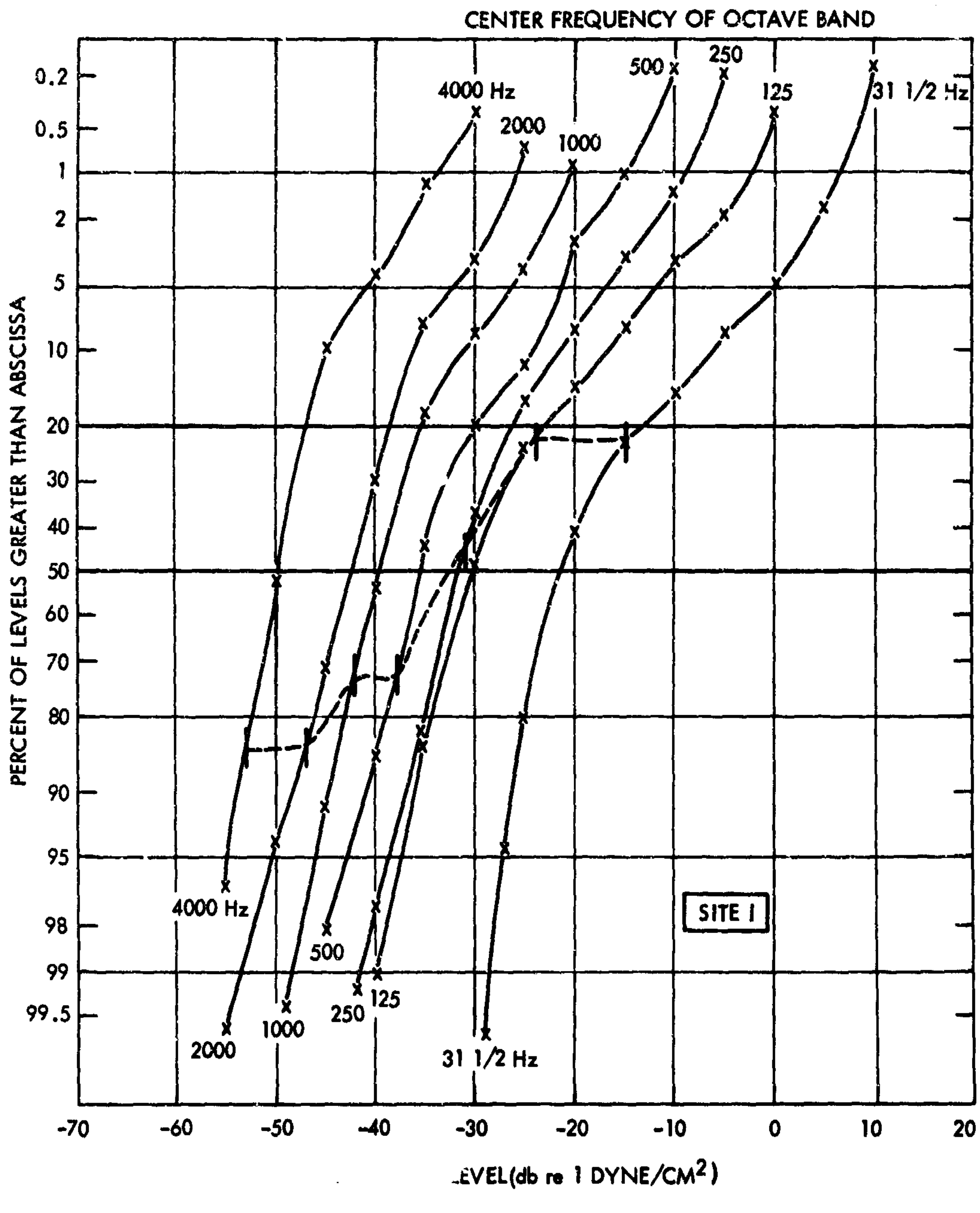

FIG. 3 CUMULATIVE DISTRIBUTION CURVES OF MEASURED AMBIENT NOISE LEVELS AT SITE I.

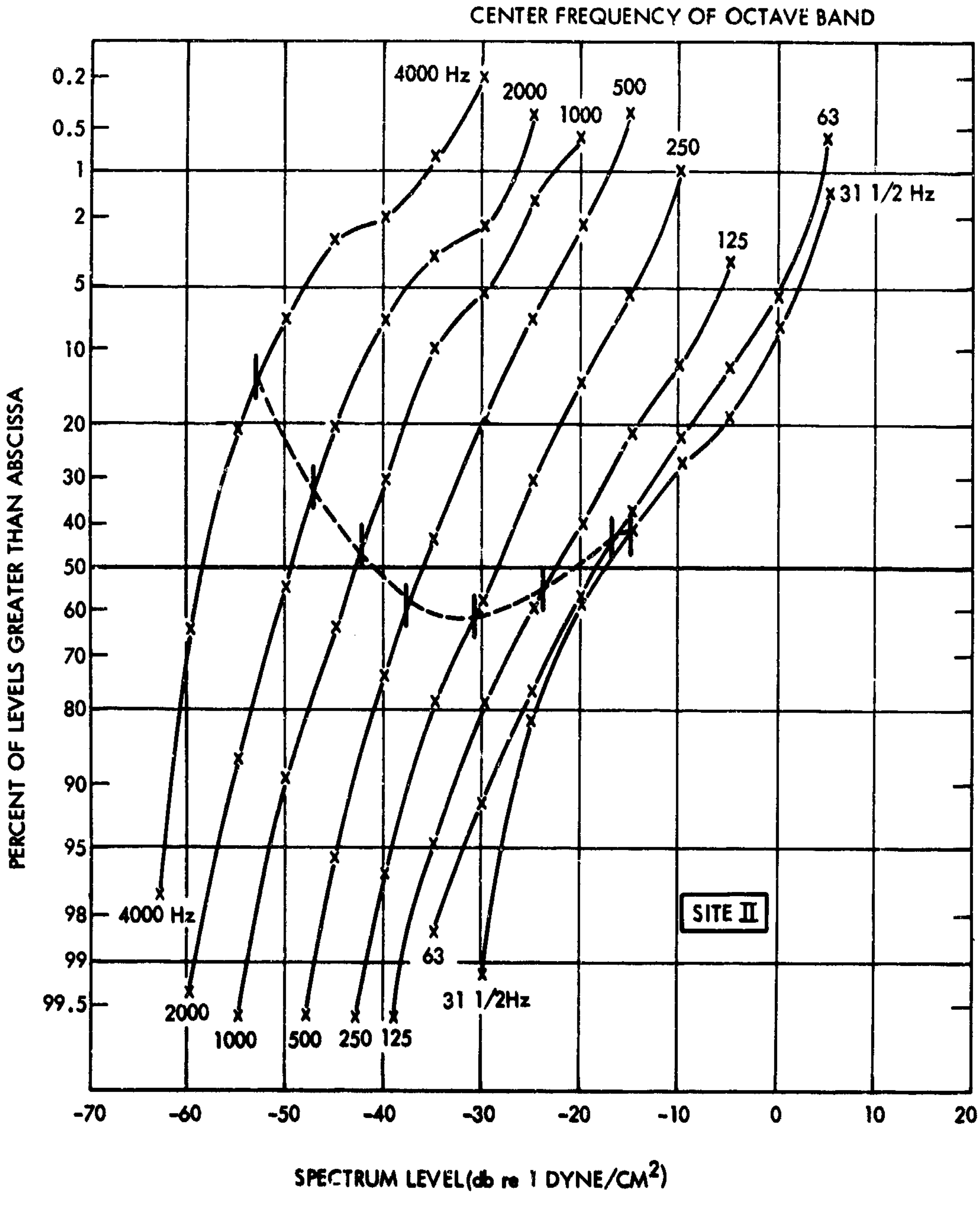

FIG. 4 CUMULATIVE DISTRIBUTION CURVES OF MEASURED AMBIENT NOISE LEVELS AT SITE II.

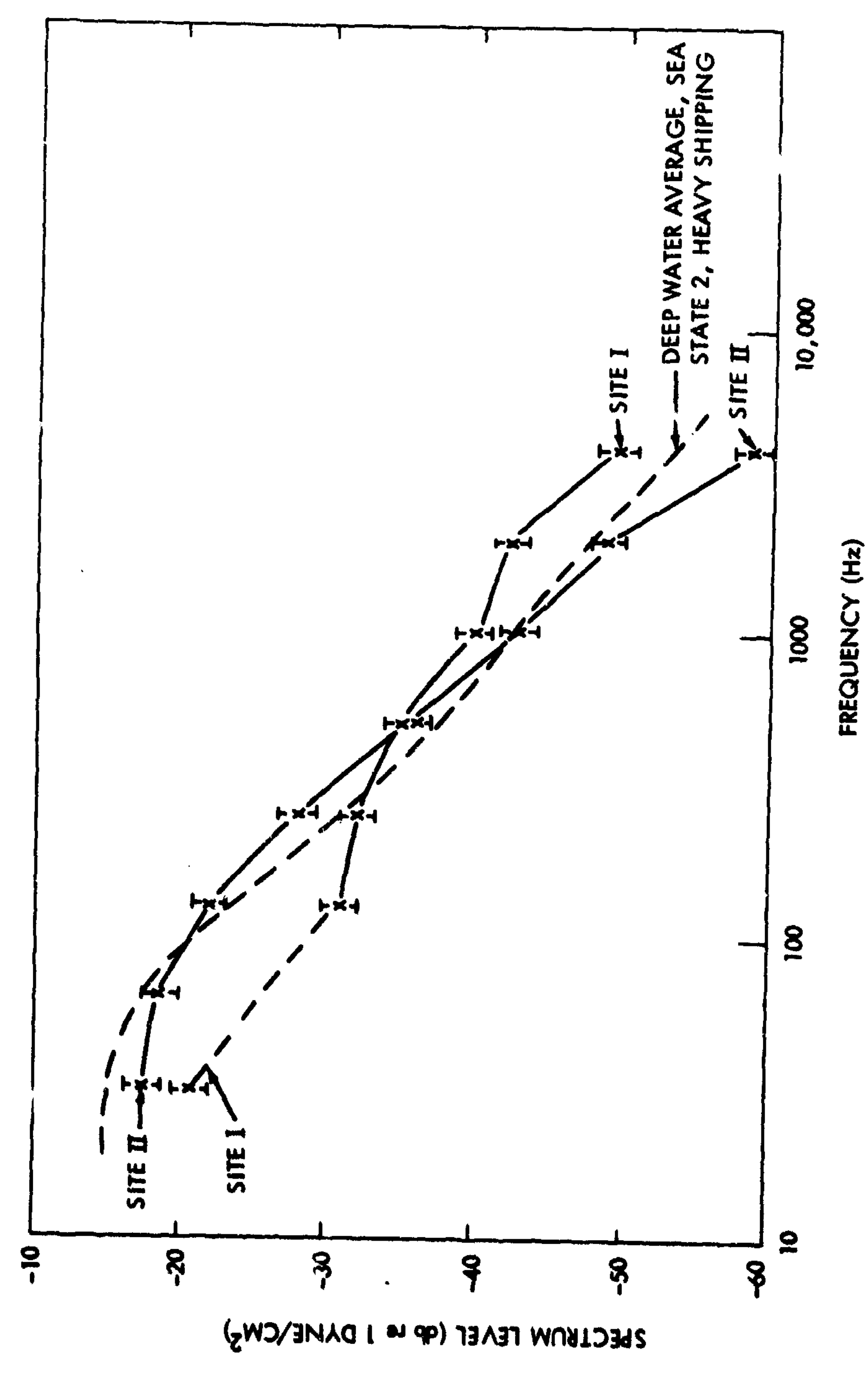

FIG. 5 MEDIAN SPECTRUM LEVELS AT SITE I AND SITE II WITH THE 5% CONFIDENCE LIMITS SHOWN AS VERTICAL LINES.

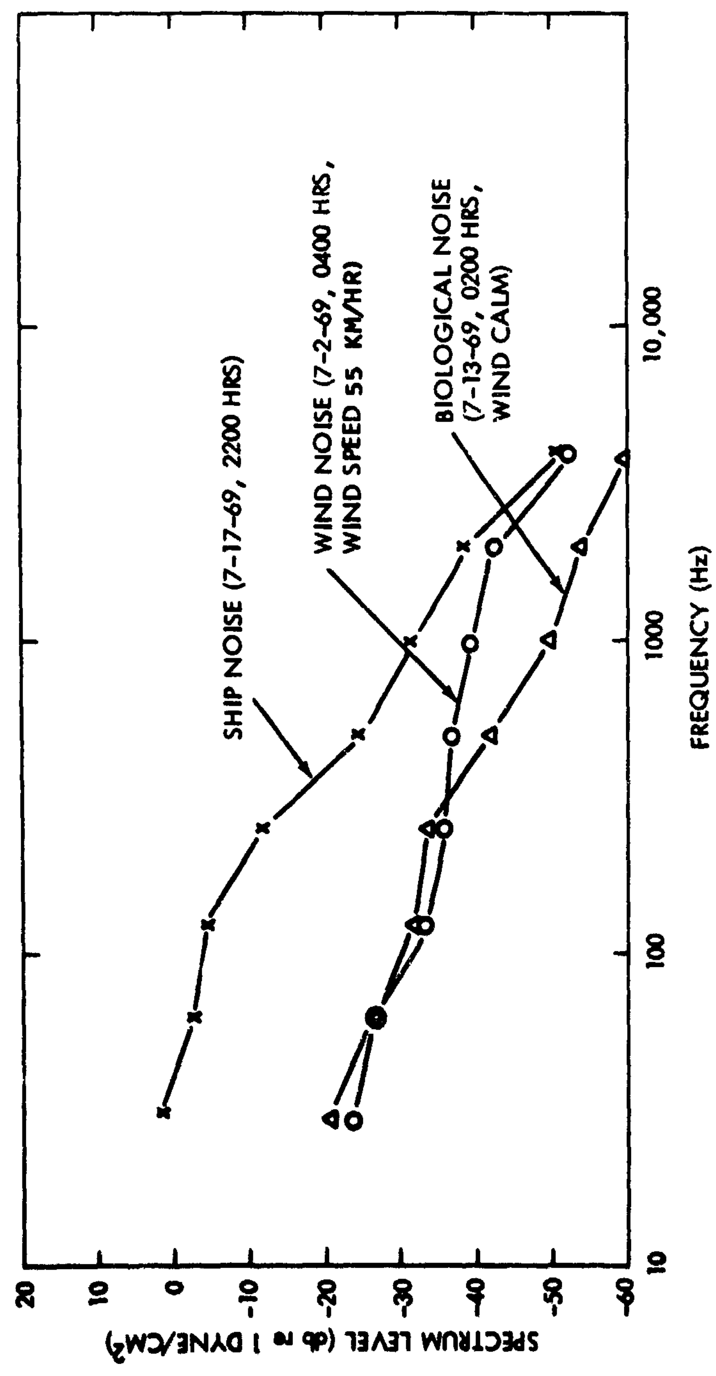

FIG. 6 OCTAVE BAND SPECTRA OF RELATIVELY PURE SAMPLES OF EACH NOISE TYPE.

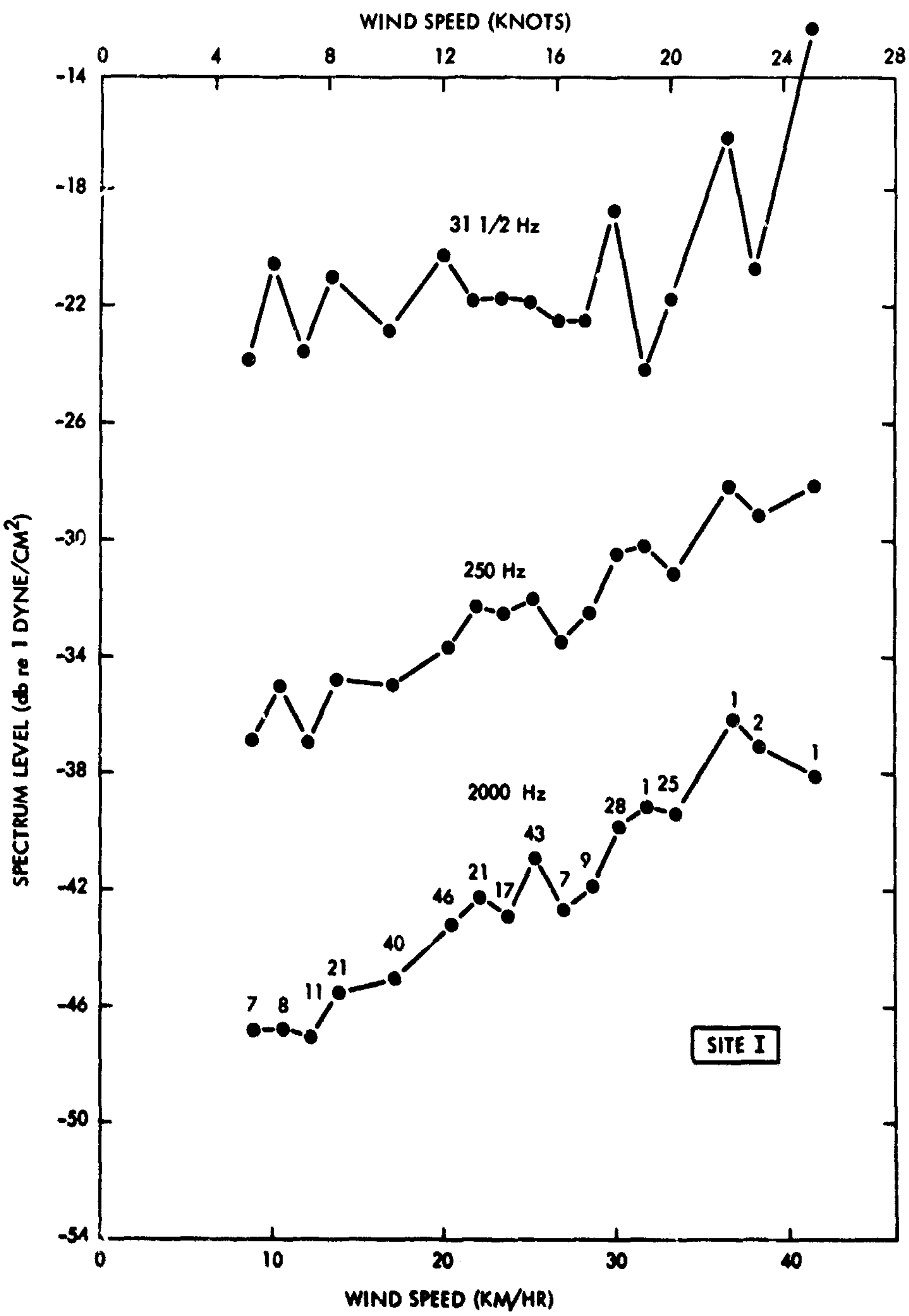

FIG. 7 MEAN AMBIENT NOISE LEVEL VERSUS WIND SPEEDS AT SITE I IN THREE FREQUENCY BANDS. THE SMALL NUMBERS GIVE THE NUMBER OF DATA SAMPLES USED IN AVERAGING.

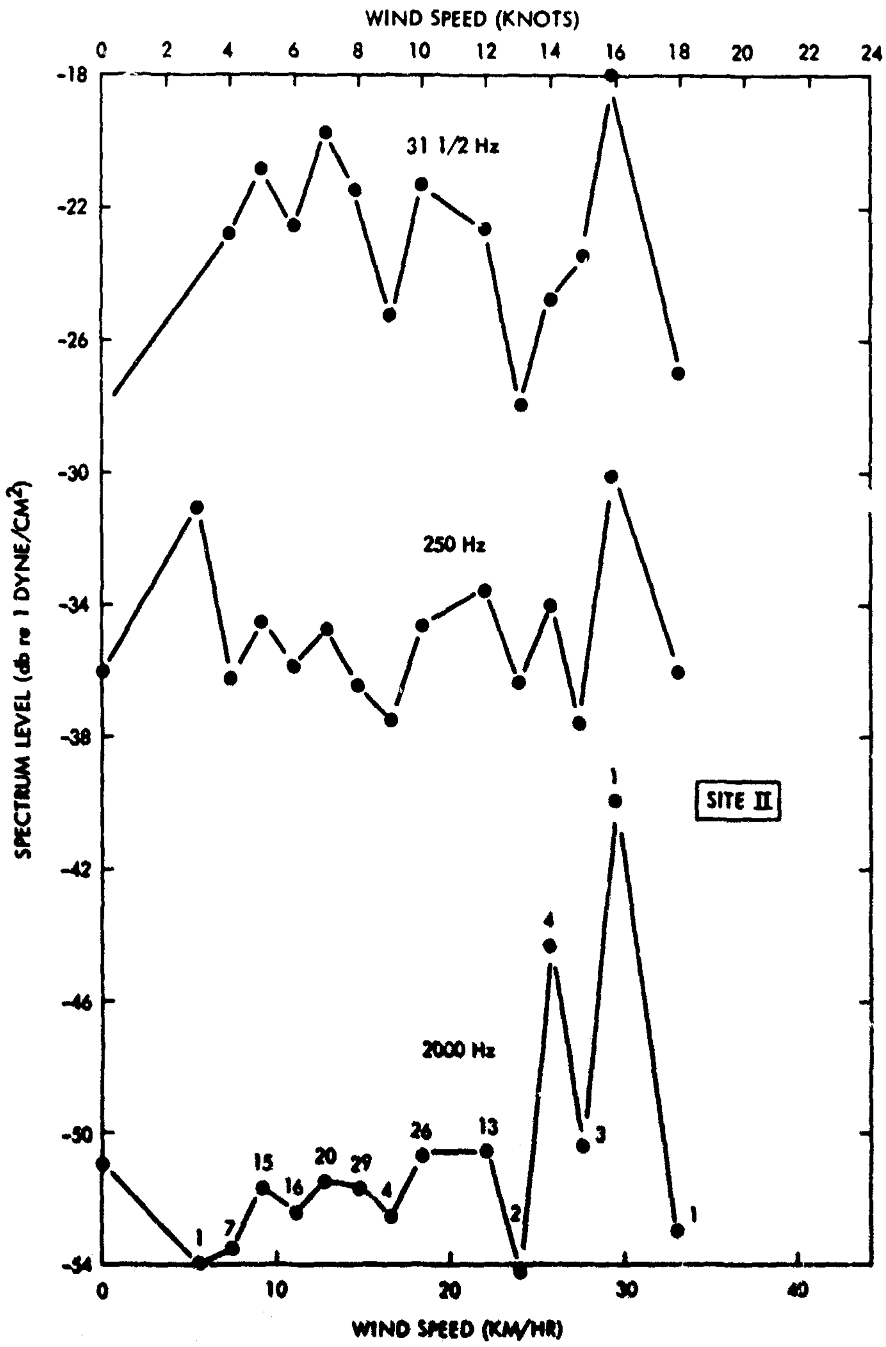

FIG. 8 MEAN AMBIENT NOISE LEVEL VERSUS WIND SPEED AT SITE II IN THREE FREQUENCY BANDS. THE SMALL NUMBERS GIVE THE NUMBER OF DATA POINTS USED IN AVERAGING.

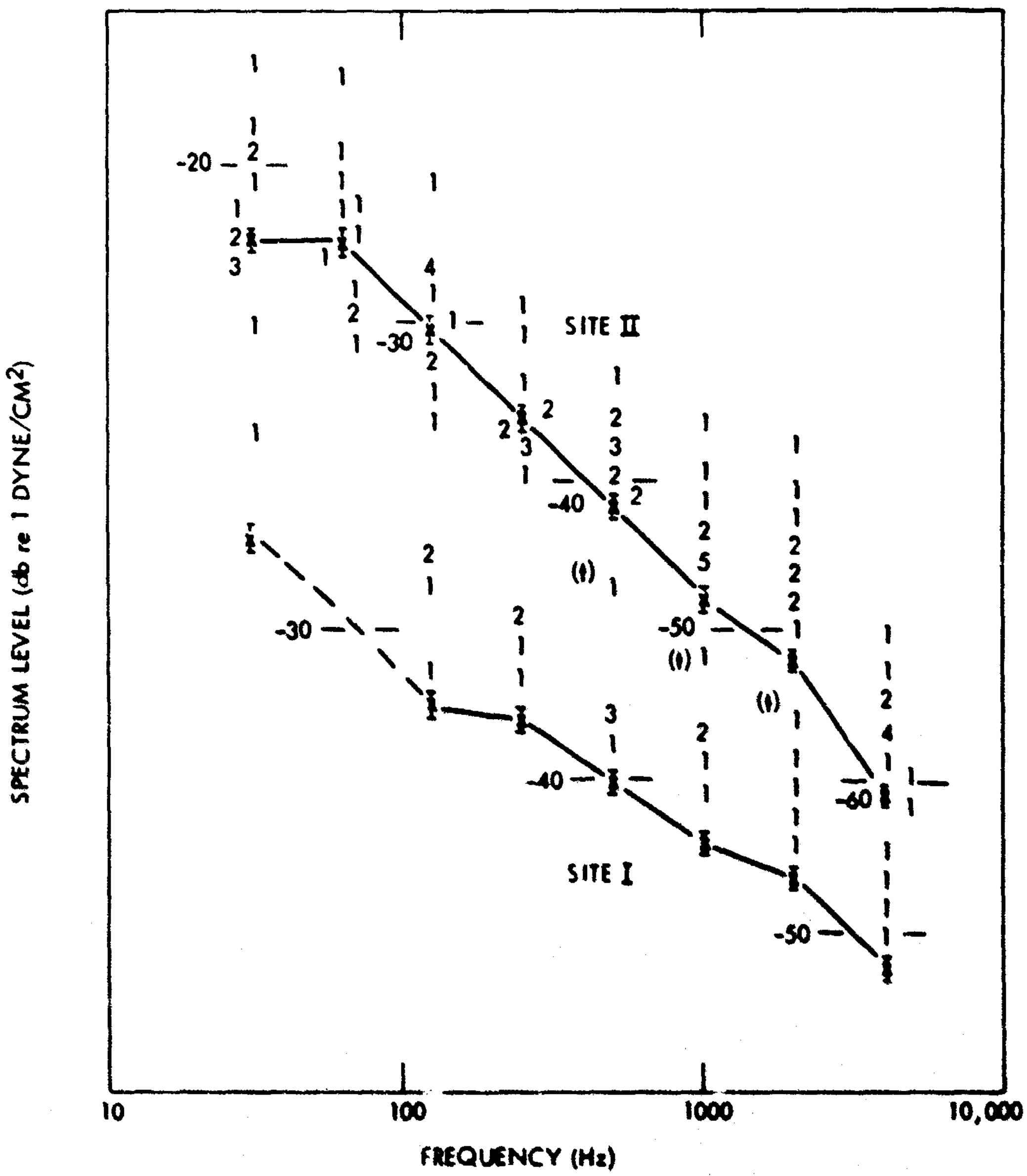

FIG. 9 EFFECT OF RAIN ON WIND NOISE AT BOTH SITES FOR WIND SPEEDS OF 10 KNOTS OR LESS. THE SMALL NUMBERS AT EACH OCTAVE-BAND CENTER FREQUENCY SHOW THE NUMBER OF RAIN SAMPLES OCCURRING AT THAT PARTICULAR LEVEL. THE CONNECTING LINES INDICATE THE MEDIAN SPECTRUM LEVELS AT EACH SITE IN THE ABSENCE OF RAIN, WITH THE 5% CONFIDENCE LIMITS SHOWN BY VERTICAL BARS.

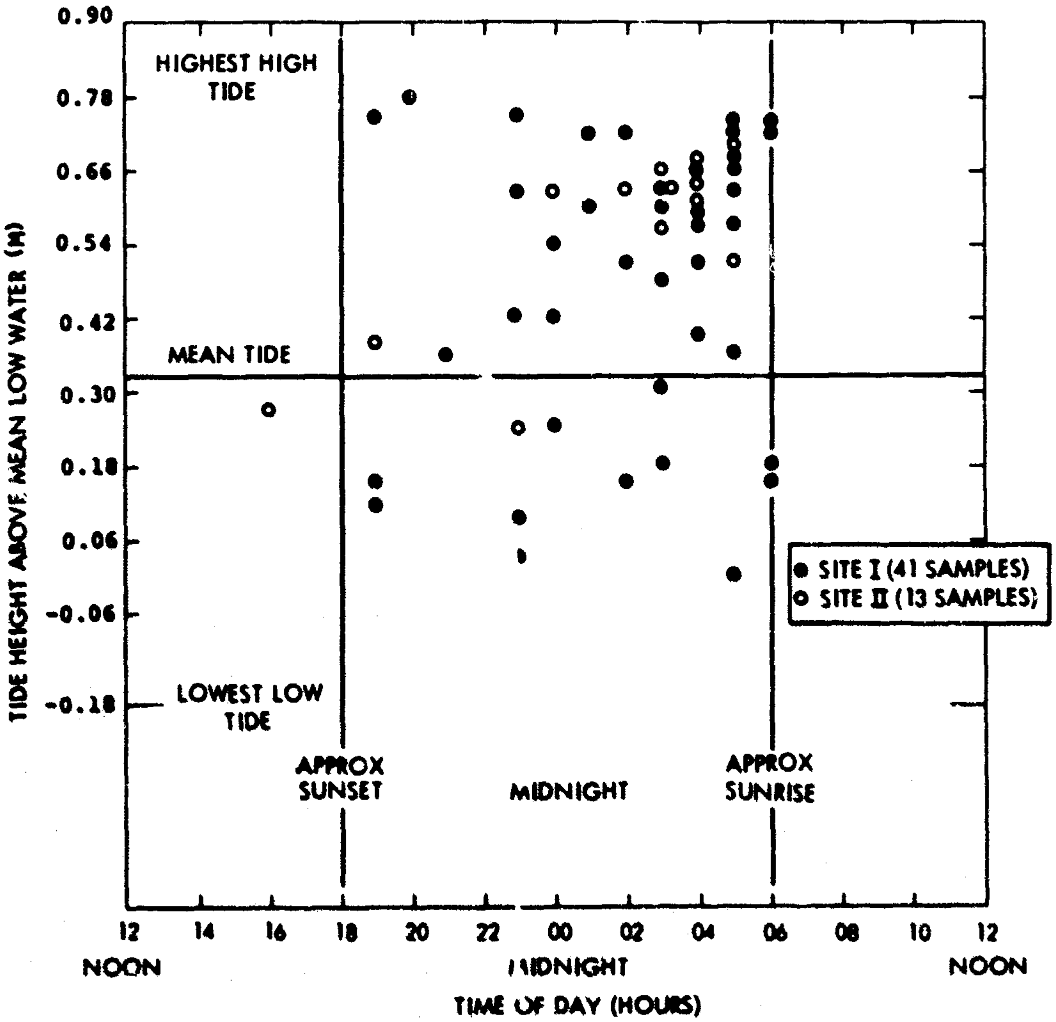

FIG. 10 OCCURRENCE OF BIOLOGICAL NOISE SAMPLES FOR BOTH SITES BY TIDE HEIGHT AND TIME OF DAY.

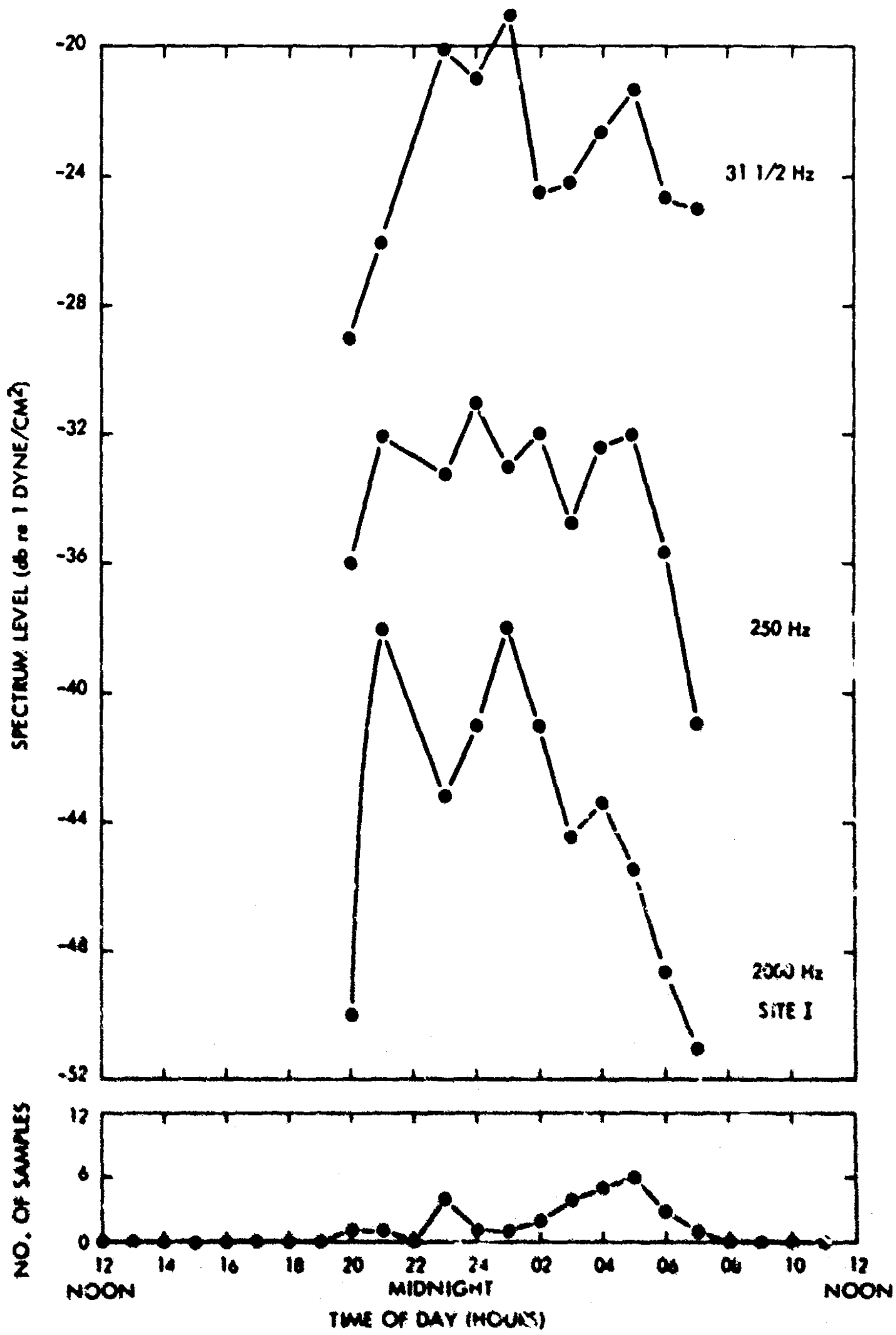

FIG. 11 MEAN LEVEL OF BIOLOGICAL NOISE AT SITE 1 BY TIME OF DAY. THE LOWER PLOT GIVES THE FREQUENCY OF OCCURRENCE OF THE SAMPLES BY TIME OF DAY.

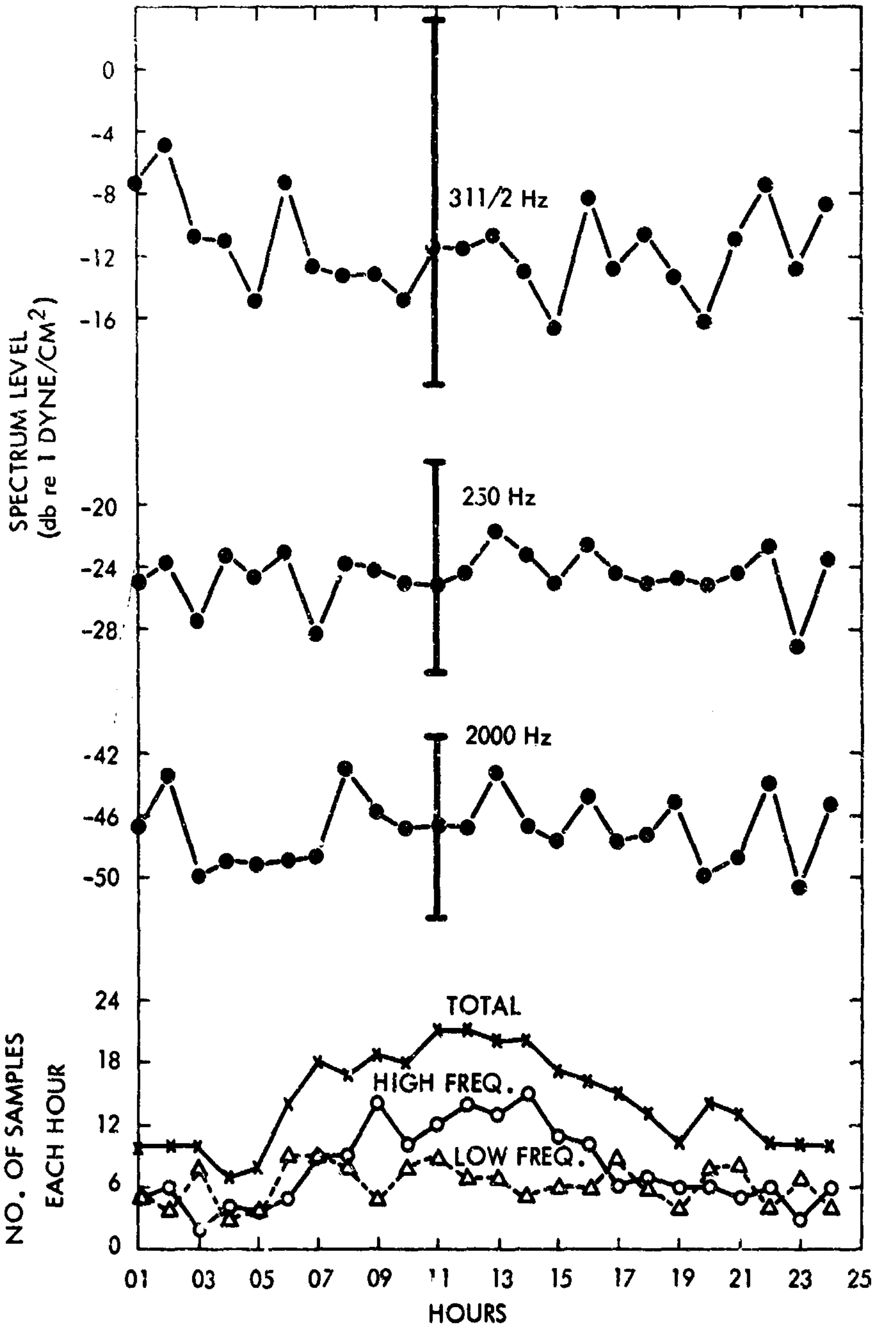

FIG. 12 MEAN SHIP NOISE LEVEL AT SITE II BY TIME OF DAY. THE VERTICAL LINES AT 1100 HOURS INDICATE THE RANGE IN LEVEL BETWEEN THE 10% AND 90% POINTS ON CUMULATIVE DISTRIBUTION CURVES OF THE 21 SAMPLE POINTS. THE LOWER PLOT GIVES THE FREQUENCY OF OCCURRENCE OF THE SAMPLES BY TIME OF DAY.

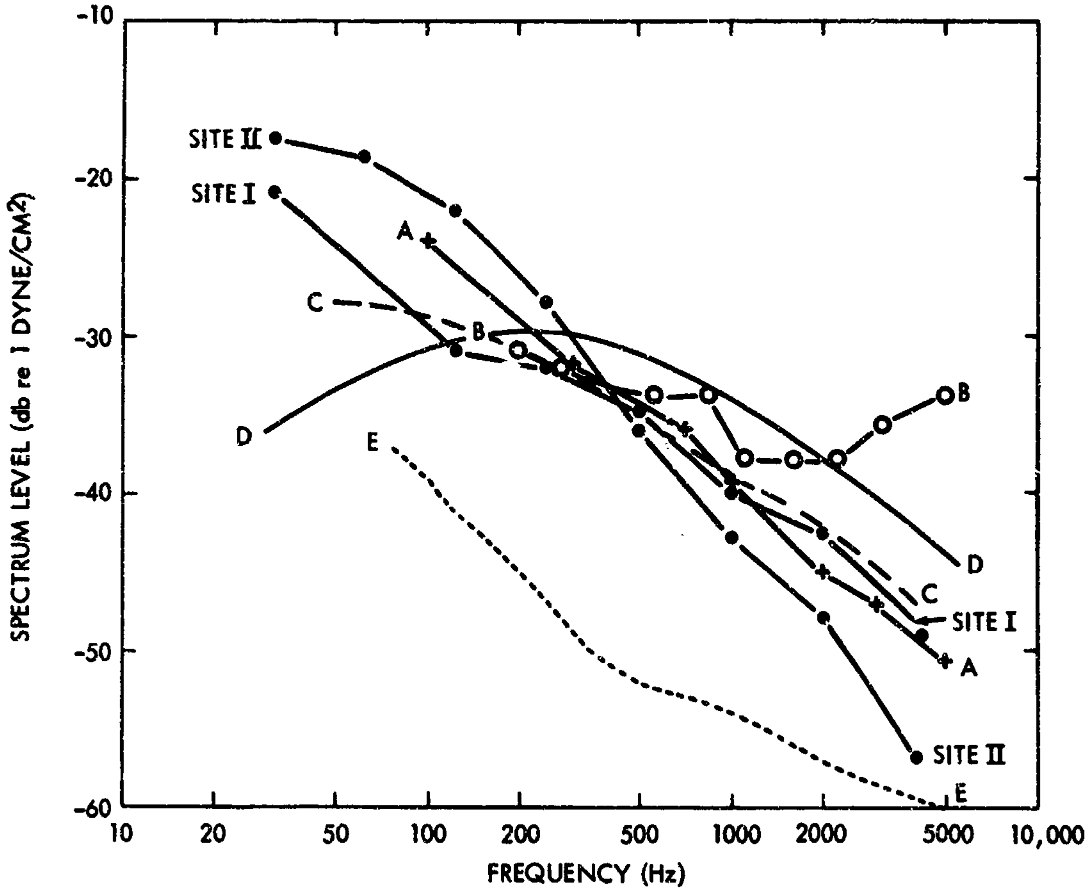

FIG. 13 COMPARISON OF PRESENT MEASUREMENTS WITH DATA PREVIOUSLY REPORTED. A-A: IN 200 m. OF WATER OFF FT. LAUDERDALE, SEA STATE 2, WITH A SHIPBOARD HYDROPHONE AT VARYING DEPTHS OF 10-100 m. (KNUDSEN, et al., 1948). B-B: BAHAMAS, WITH SNAPPING SHRIMP PRESENT, (KNUDSEN, et al., 1944). C-C: AVERAGE OF 5 UNSPECIFIED LOCATIONS WITH DEPTHS LESS THAN 180 m. AND AVERAGE SPEED WIND 11 KNOTS, (WENZ, 1962). D-D: WIND NOISE IN 36-51 m. ON THE SCOTIAN SHELF, WIND SPEED 12 KNOTS, (PIGGOTT, 1964). E-E: AVERAGE OF TWO STATIONS OFF SOUTHEAST ASIA, DEPTHS OF 84 and 105 METERS, (CATO, 1968). F-F: LOCATIONS 2-3 km WEST OF BIMINI, BAHAMAS, HYDROPHONES AT 25 AND 400 METERS, (DANN, 1969).

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11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	Air Systems Command

13. ABSTRACT

The underwater noise at two nearby sites off the Atlantic coast of Florida has been recorded at hourly intervals over periods of several weeks. At these sites, the levels of the noise were found to be highly variable, in keeping with the dynamic, changeable nature of the acoustic environment. Both the statistics of the ambient background in different octave bands, and the characteristics of the sources of noise as determined by listening to the hourly noise samples, have been obtained. For example, biological noise was found to be more prevalent during the night when the tide was high than at other times. Also, in the absence of shipping and biological sources, the level of high frequency noise was found to increase with wind speed, as it is well-known to do in deep water. Still, in spite of the busy, active underwater environment, the noise levels compare favorably with those previously reported for other shallow-water locations.

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